

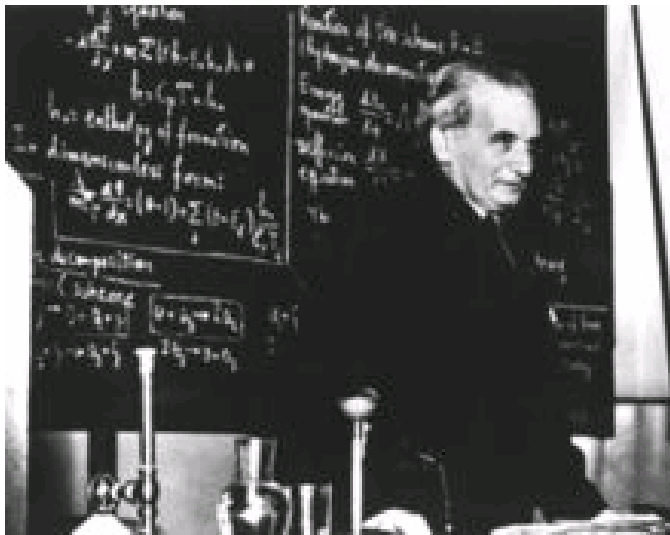


# **Overview of iGEM and synthetic biology**

Andrew Hessel

University of Lethbridge, July 19 2007

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*A Scientist discovers that  
which exists; an Engineer  
creates that which never was.*

-- Theodore Von Kármán

**“Synthetic biology** is an emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems.”

# Technology of synthetic biology

DNA is fundamental...

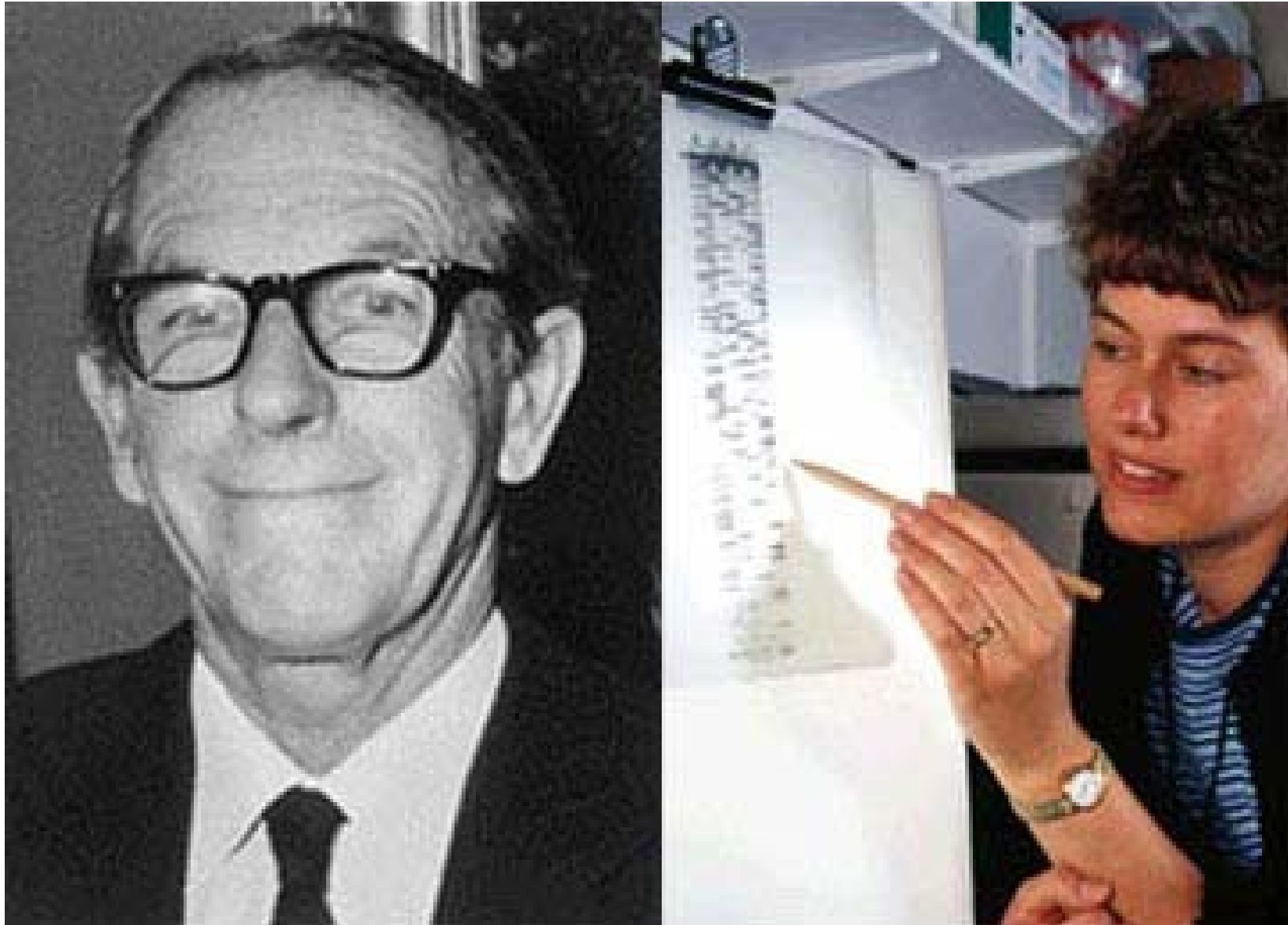
It is the machine language program  
for biochemical processes

The ability to manipulate this one molecule allows virtually anything biological to be engineered!

DNA is to biology as the electron is to computing



# Reading code





1980  
500 bp/day (manual)



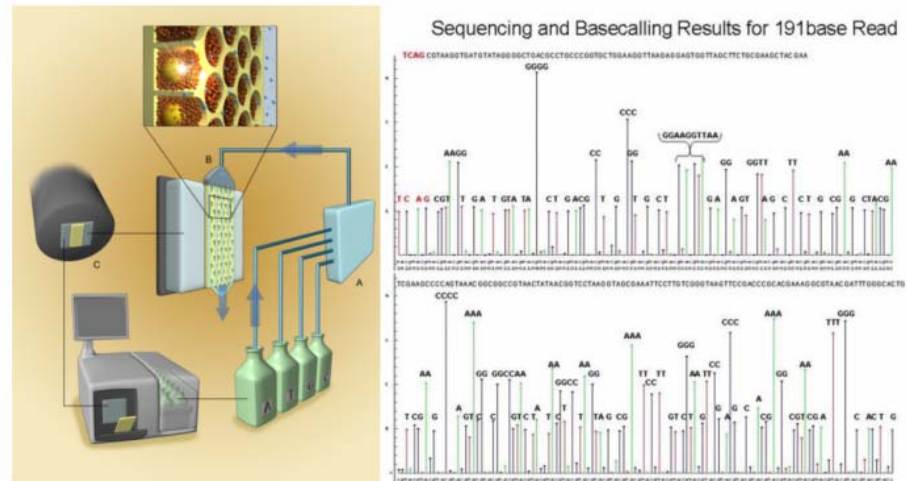
1987  
36,000 bp/day (semi-auto)



1995  
144,000 bp/day (semi-auto)



1998  
500,000 bp/day (automatic)



## 2007 – Sequencing by Synthesis



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# Comprehension



Volume 16 Number 5 1988

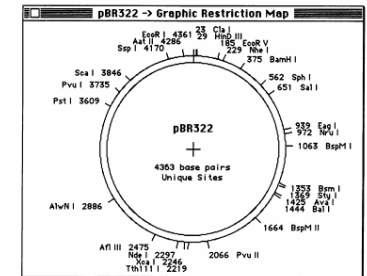
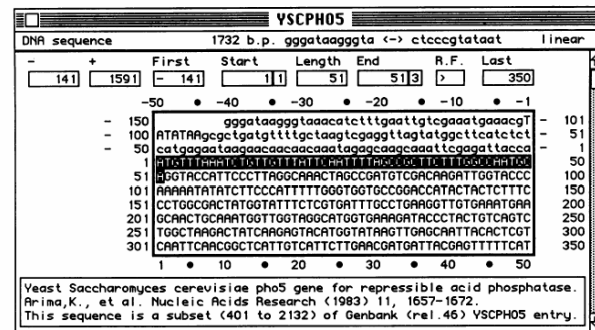
Nucleic Acids Research

'DNA Strider': a 'C' program for the fast analysis of DNA and protein sequences on the Apple Macintosh family of computers

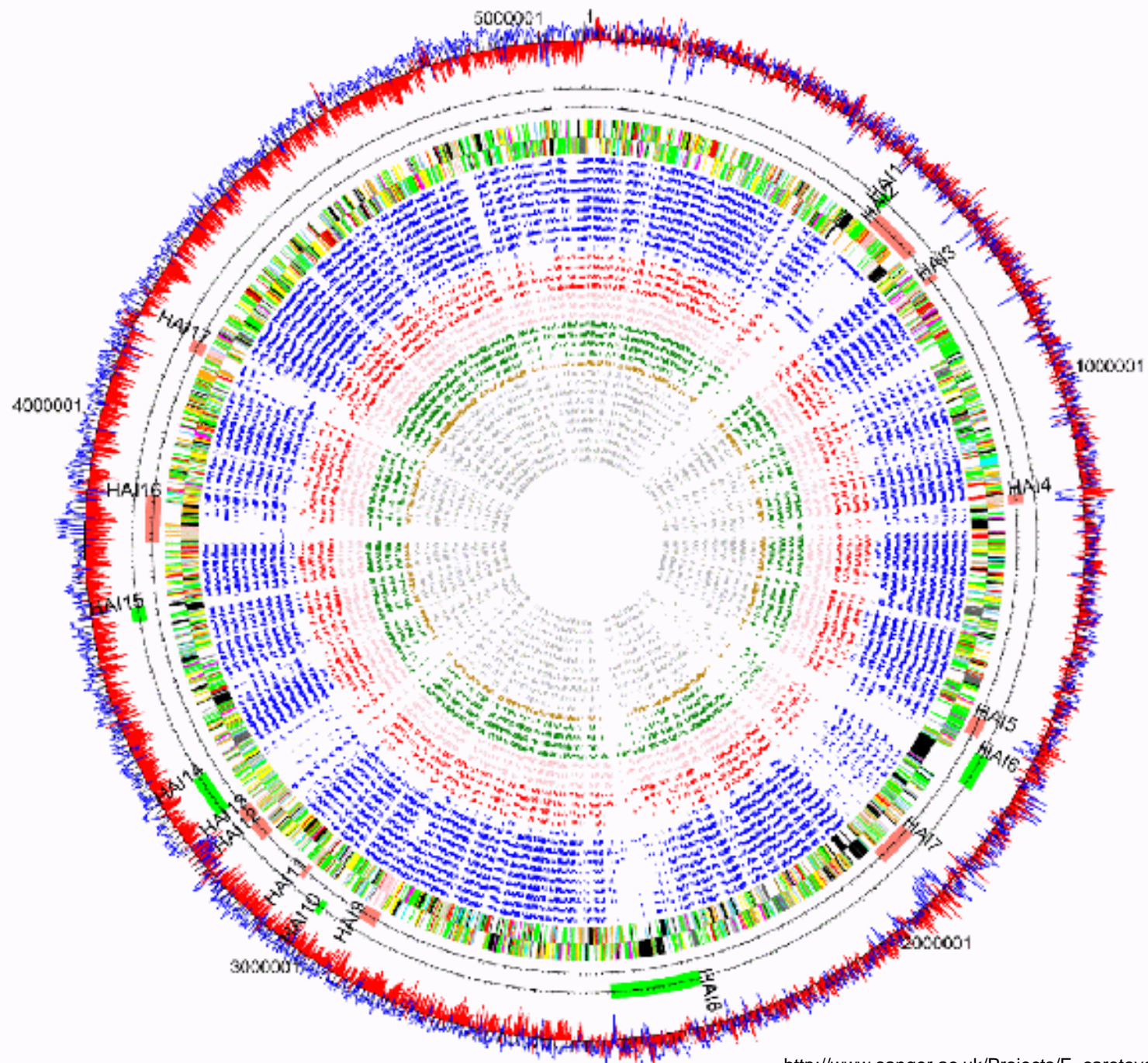
Christian Marck

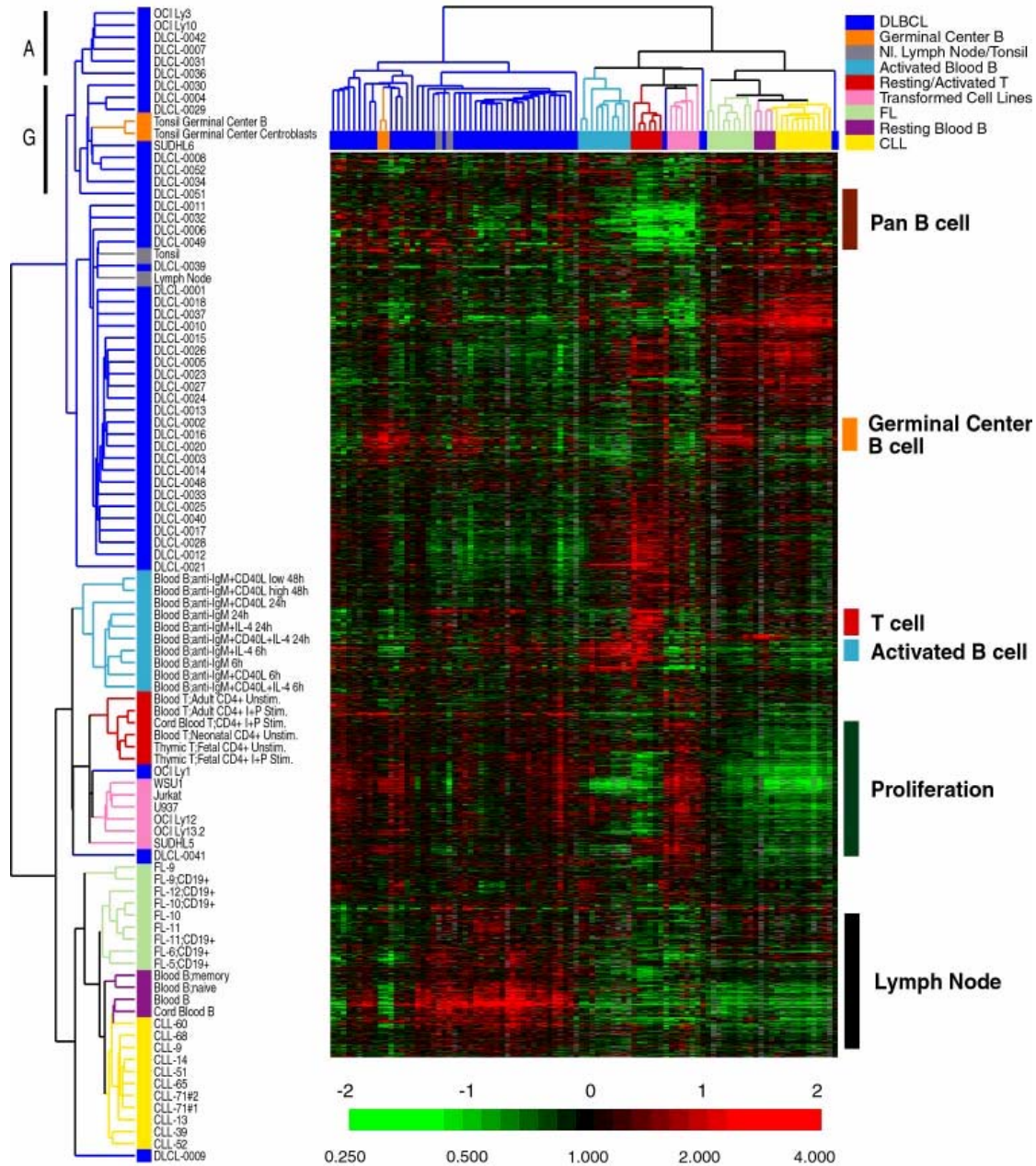
Service de Biochimie, Bâtiment 142, Département de Biologie, Centre d'Etudes Nucléaires de Saclay, 91191 Gif-sur-Yvette Cedex, France

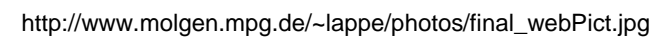
Received August 17, 1987; Revised and Accepted November 15, 1987



280.6 TFLOPS with 131072 nodes

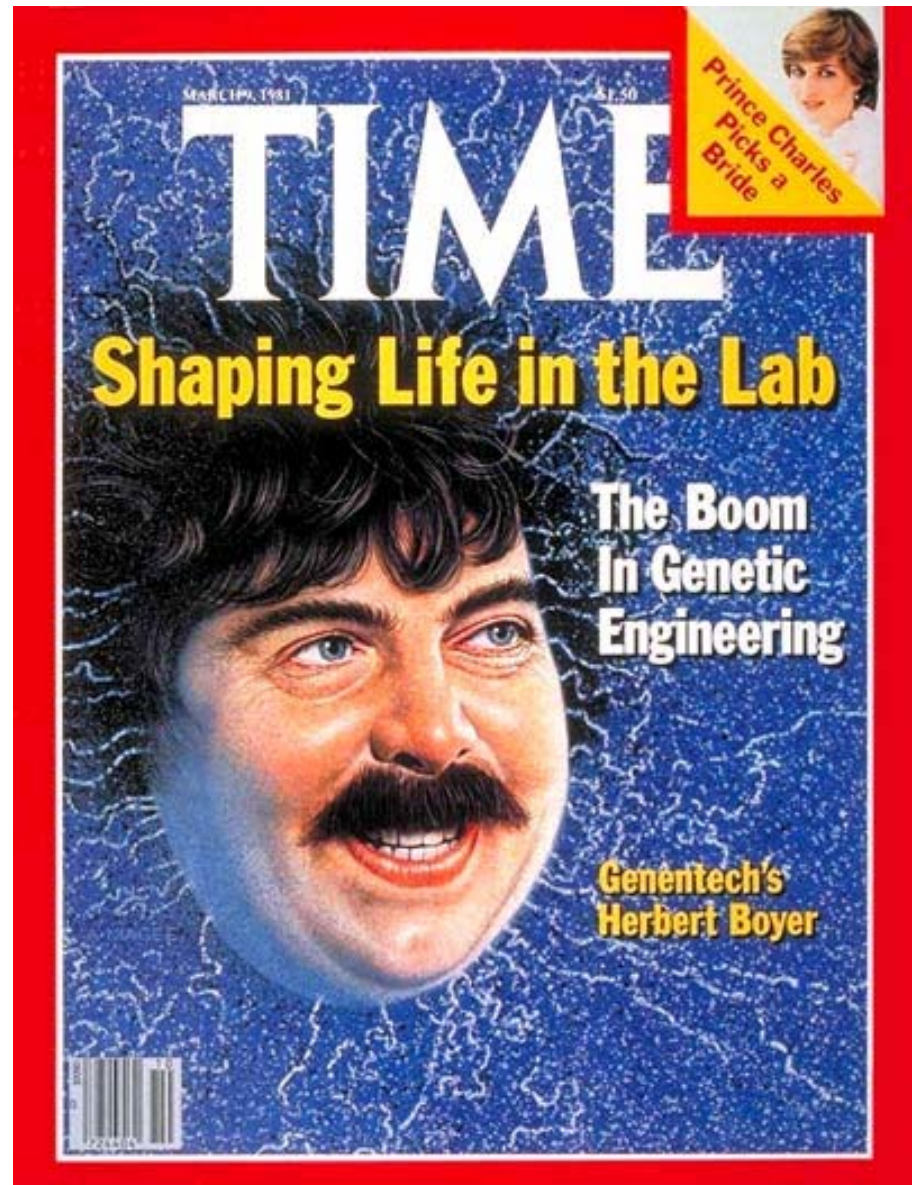
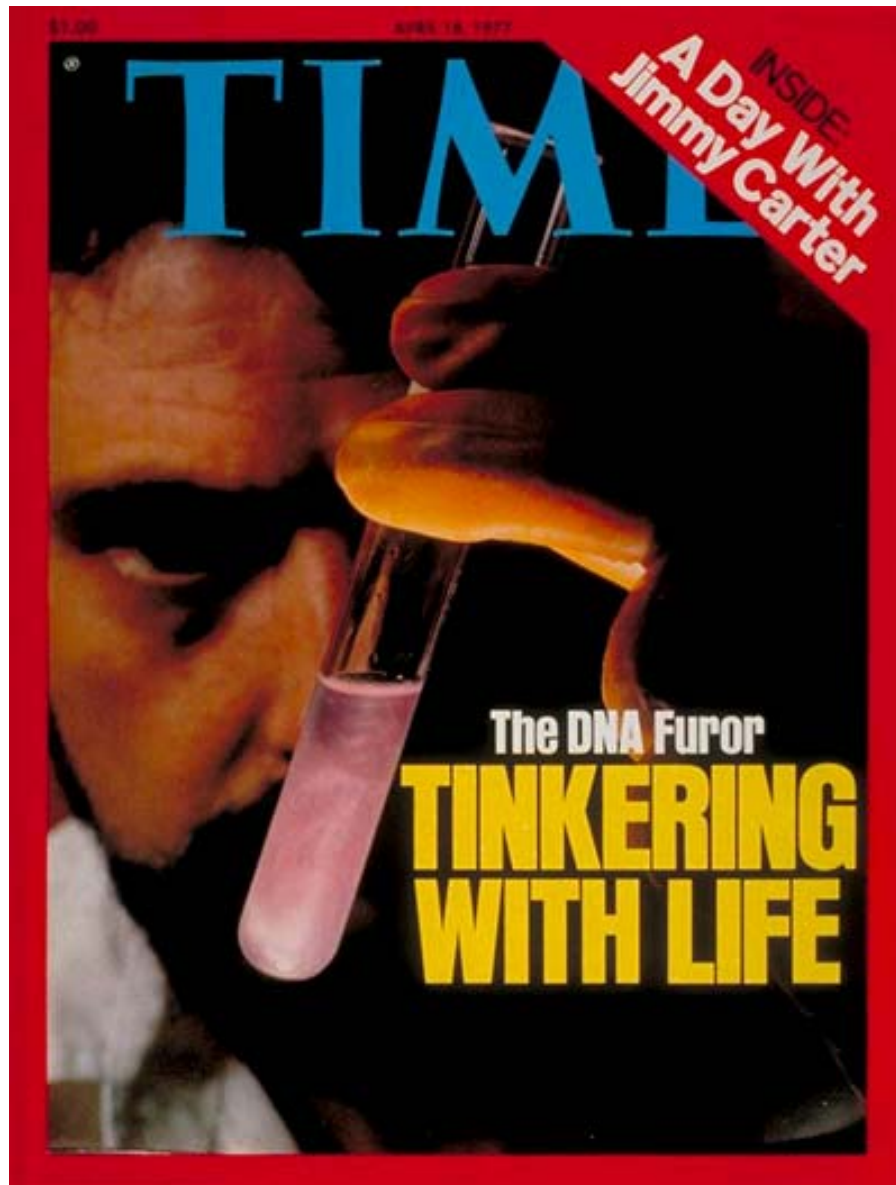






Writing code: synthesis

If we can't build it, we don't understand it.

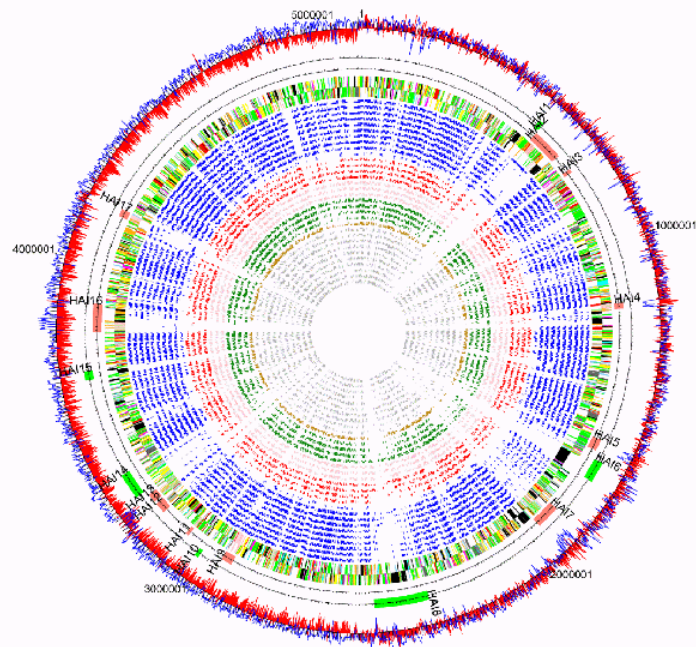




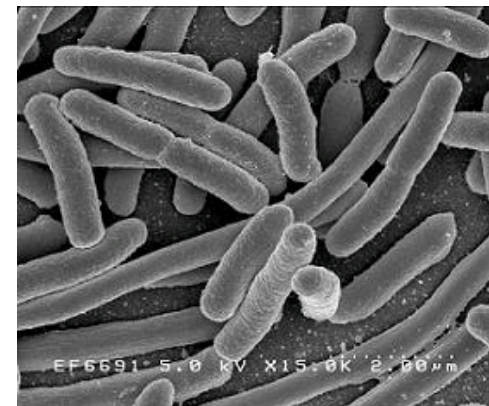
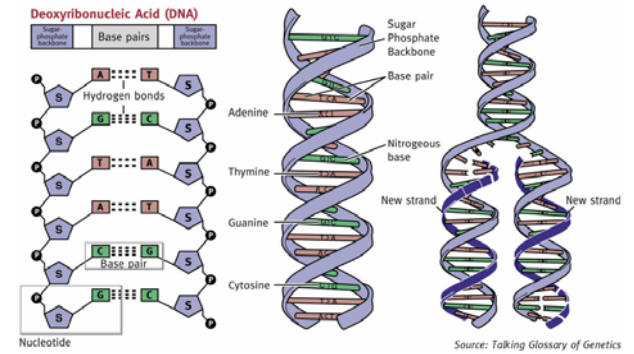
if you can **W**RiTe **D**Na,

You **'rE** **nO** **LONGER** **liMi****TED**

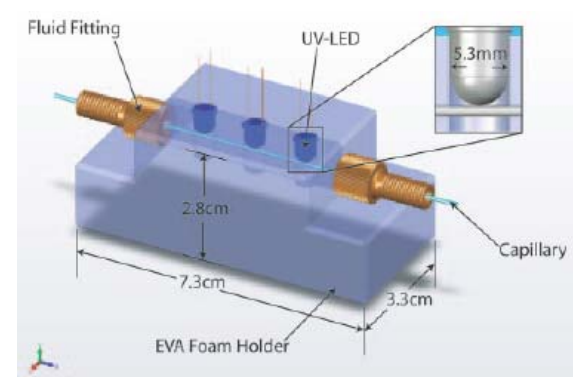
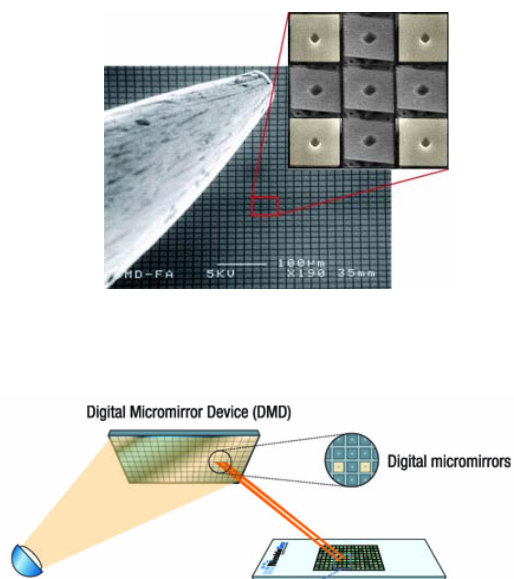
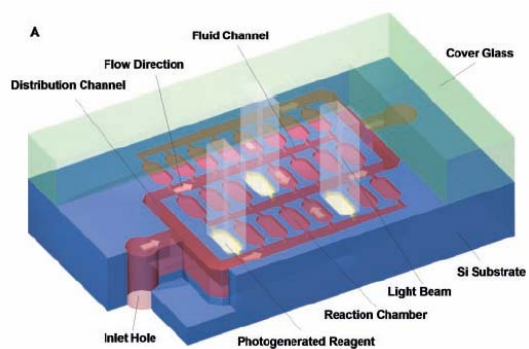
to " **IS** " but **TO** **what** you **could** **MAKE** •

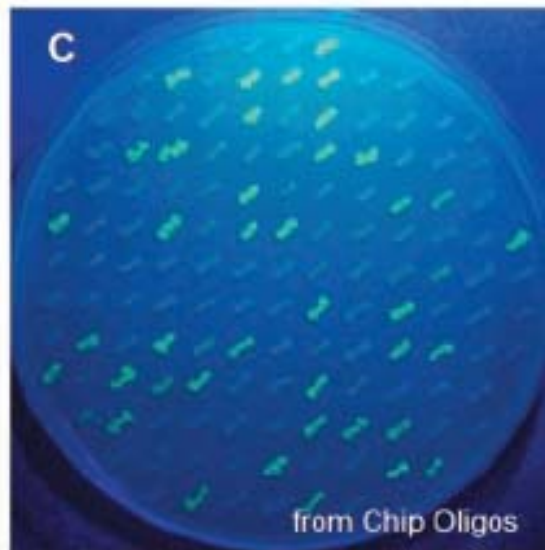
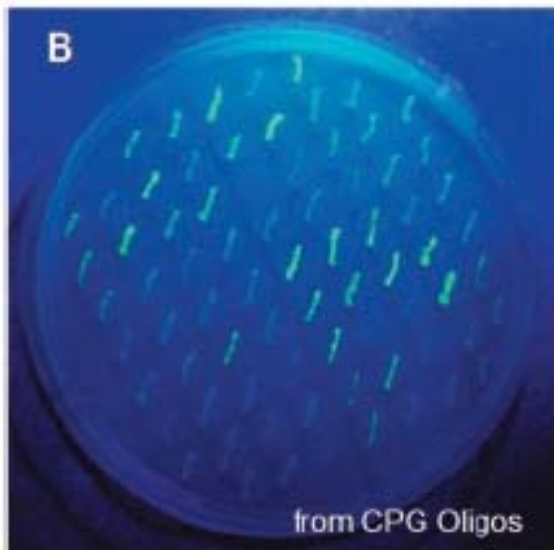


Digital DNA “design”



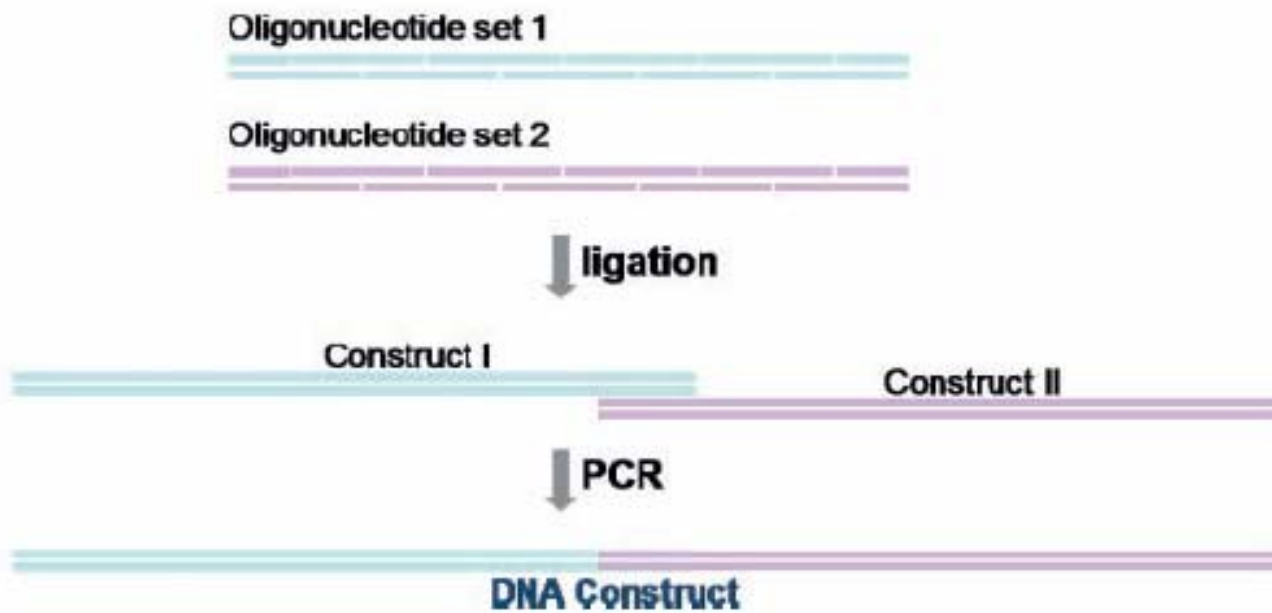
Physical DNA and outputs



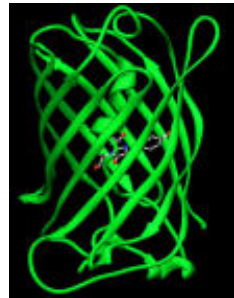


EGFP gene 714 bp

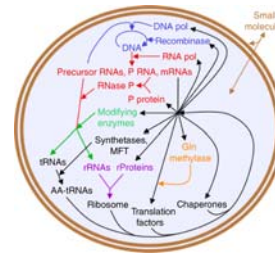
**D**



# Applications dependent on synthetic capabilities

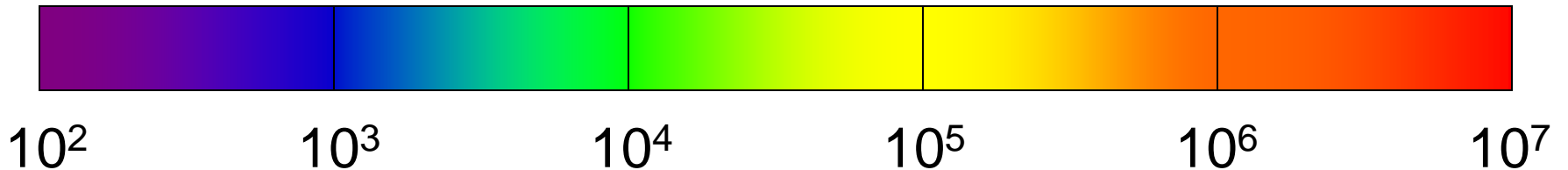


single genes\*



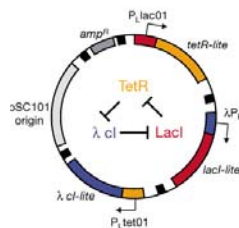
minimal life

base  
pairs



genetic circuits, viruses, GEMs

Engineered organisms



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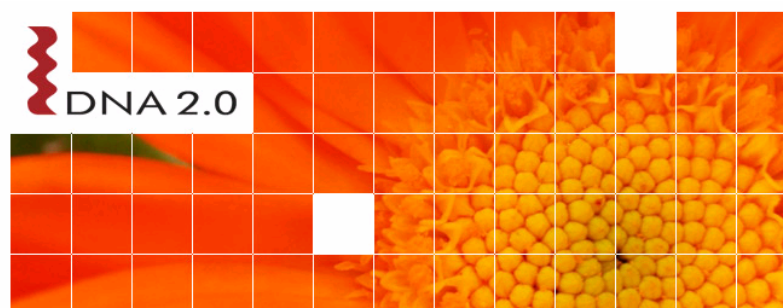
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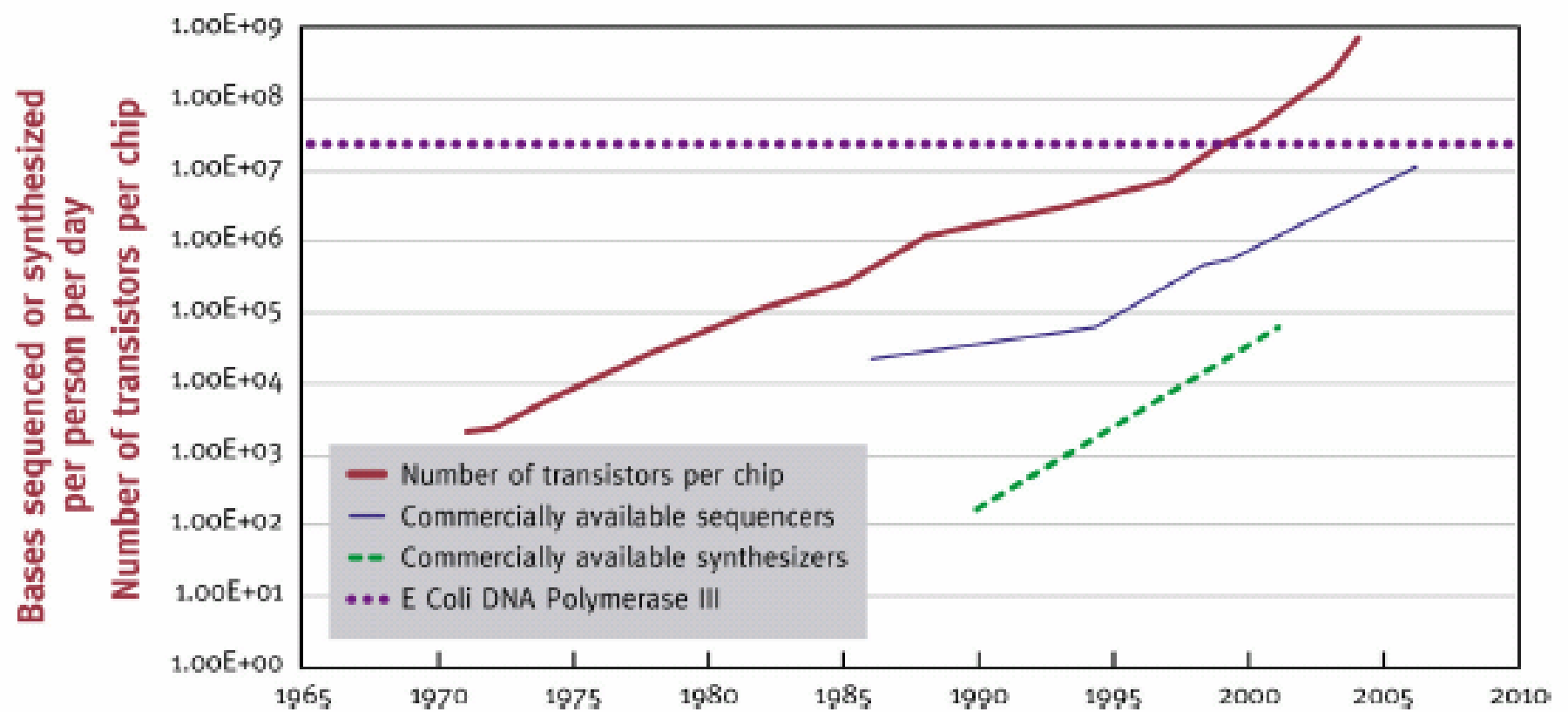


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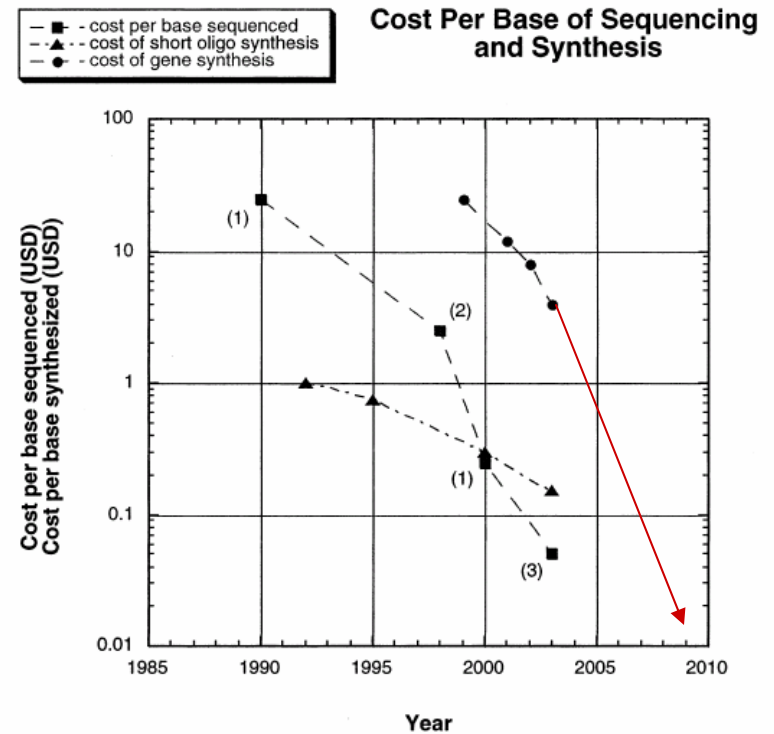
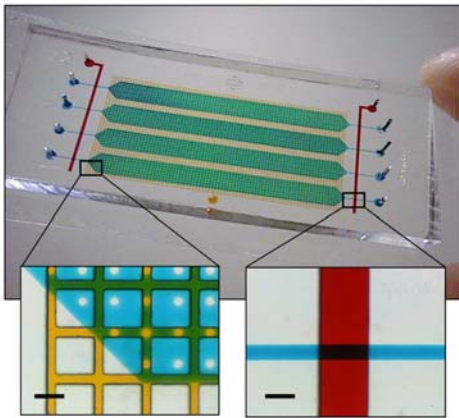
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Source: R. Carlson, Bio-era.

- -5 years: 0.5 - 5kb, \$10-\$15/bp
- 0 years: 50 - 500kb \$0.50-\$1/bp
- +5 years: 5mb - 5gb <\$0.0001/bp

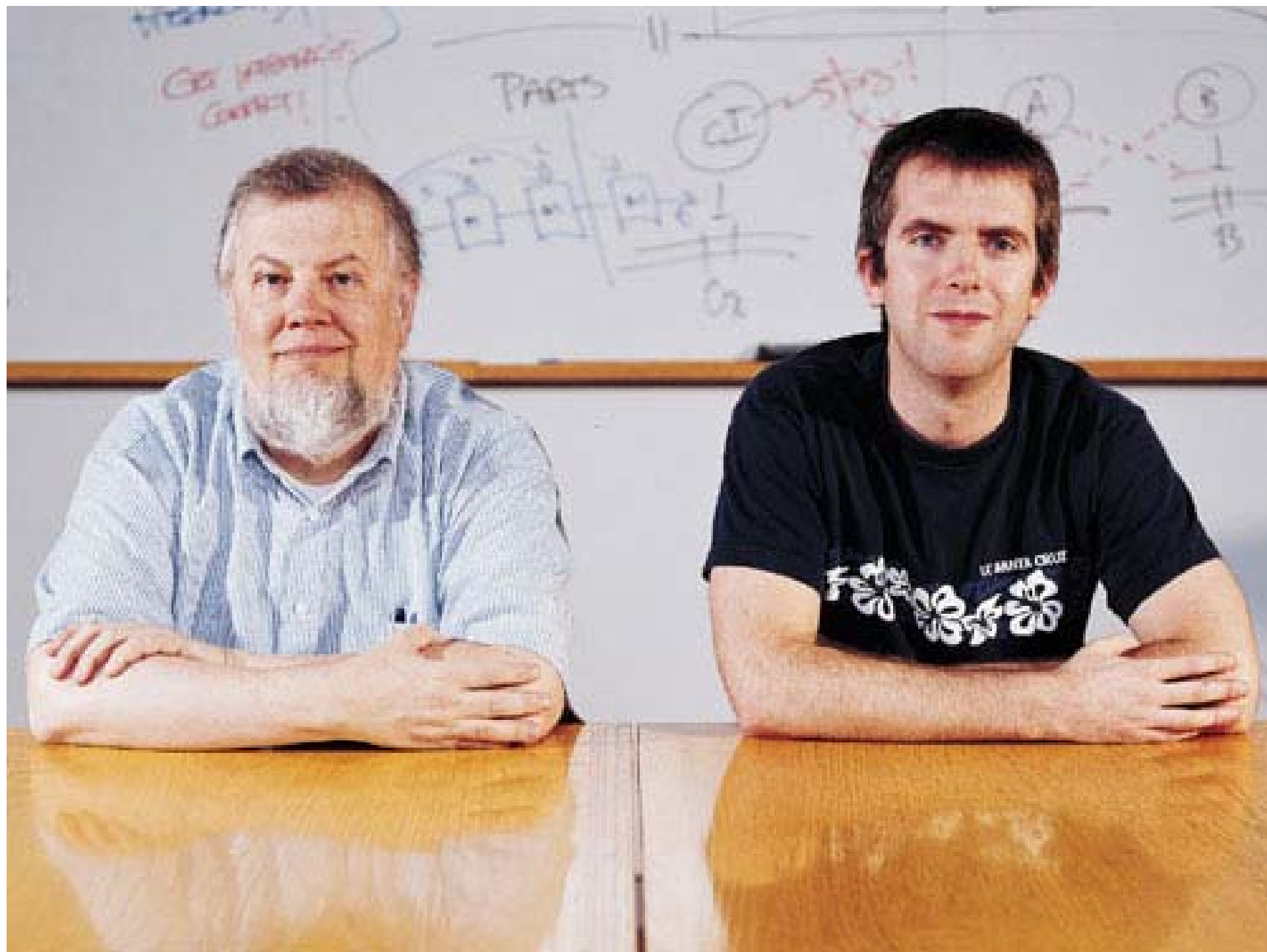


Carlson, R. (2003) The Pace and Proliferation of Biological Technologies

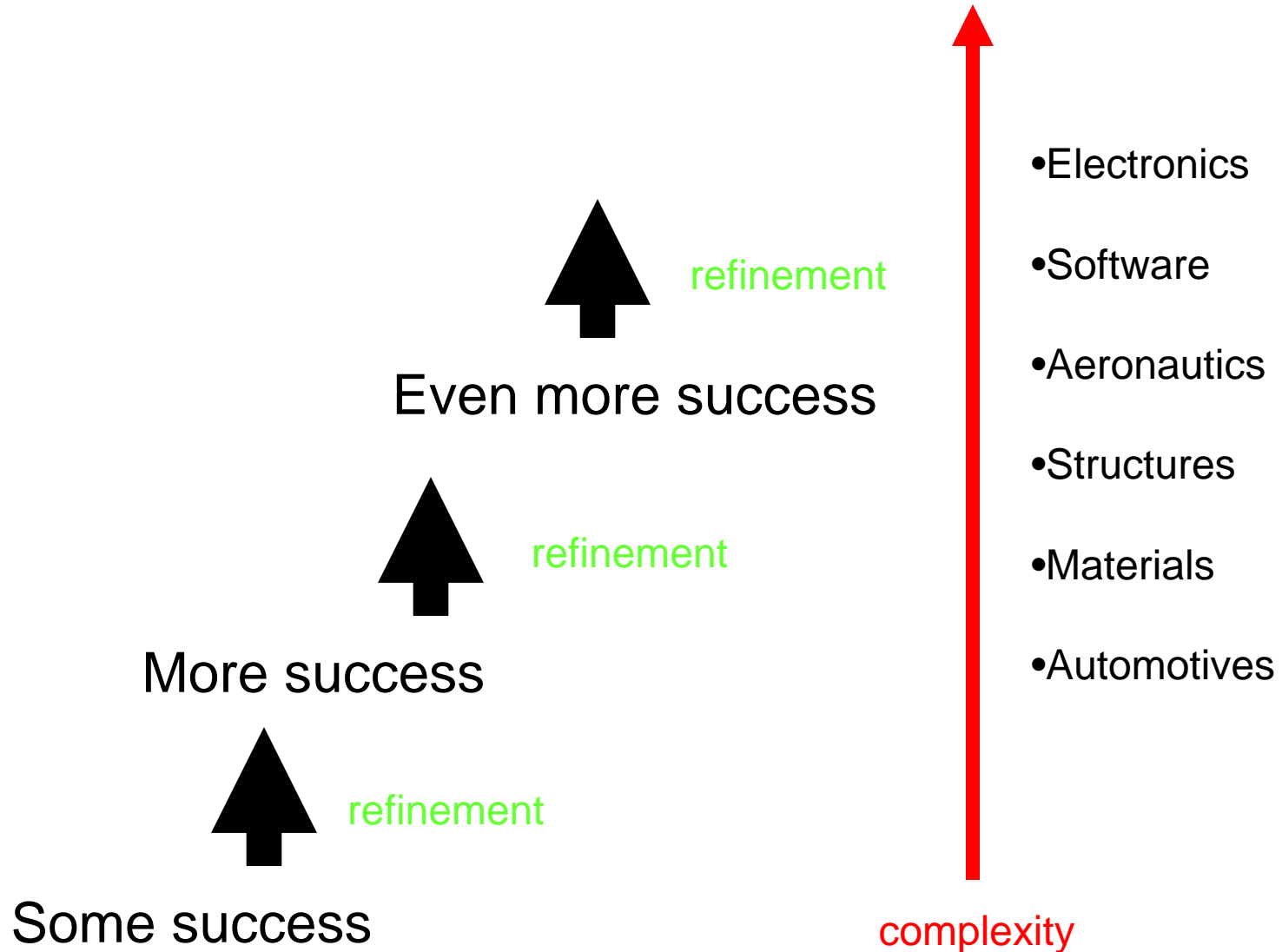


Sources: Source: R. Carlson, G. Epstein, A. Yu (2005)

# Engineering philosophy



# Engineering process...



# F1760

Sender Device

## B0015

terminator

Name: B0015

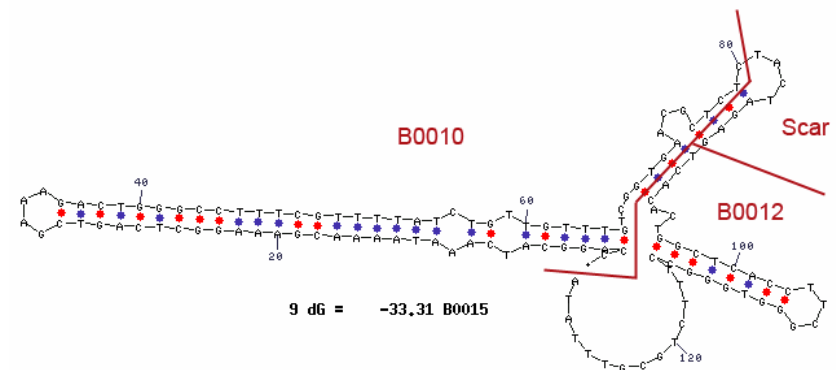
Type: Double terminator

Length 129 bp

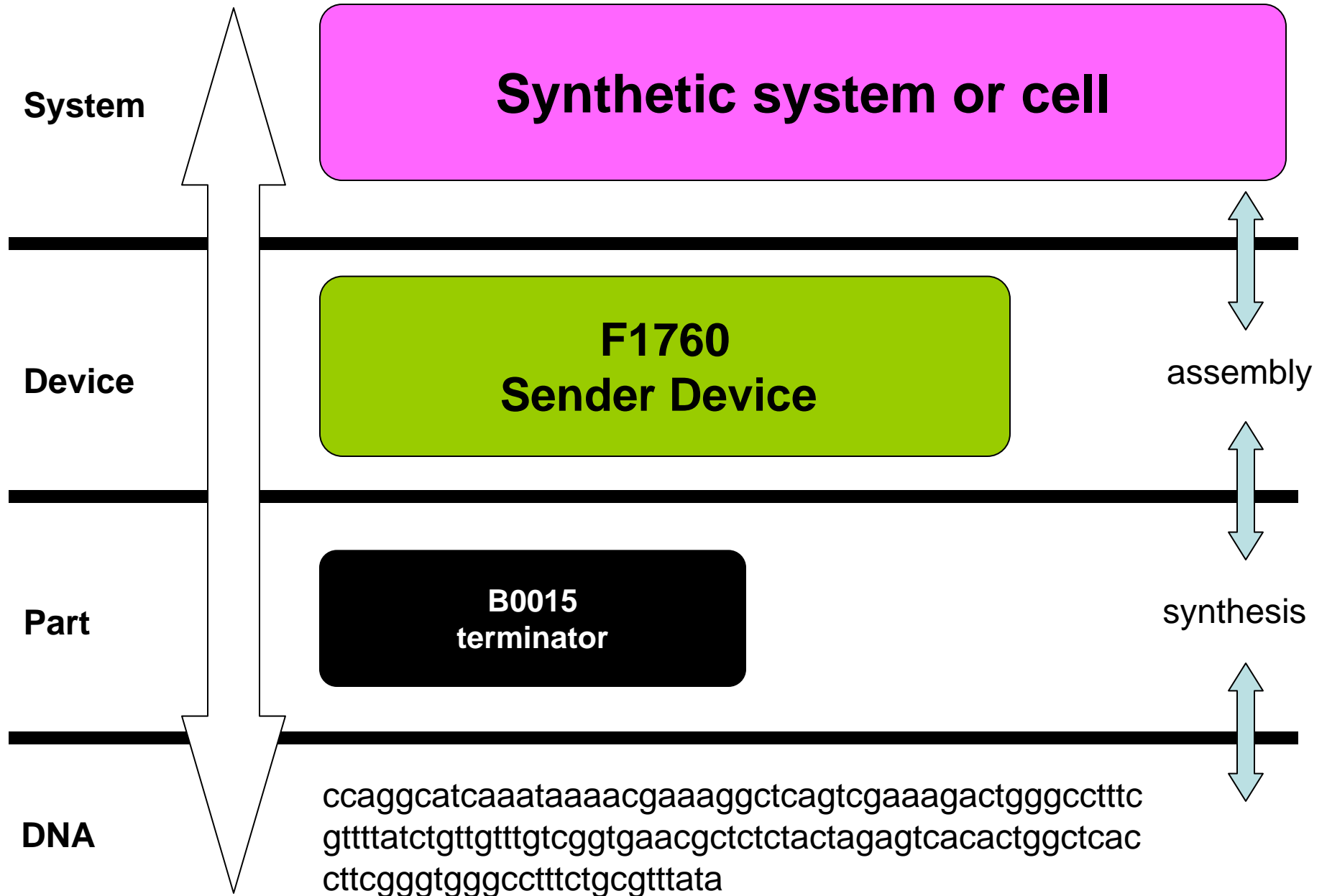
Designed by: Reshma Shetty

Forward efficiency: 0.984

Reverse efficiency: .295



# STANDARDIZED DATA





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## Transcriptional Regulators

Available repressible regulators (normally ON) -?-

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-?-	Name	Description	Direction	Control -?-	Output Low High	Length
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_I14032</a>	promoter P(Lac) IQ	Forward			37
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_R0040</a>	promoter (tetR, negative)	Forward	aTc, tetracycline		54
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_R0051</a>	promoter (lambda cl regulated)	Forward	lambda cl		49

Available inducible regulators (normally OFF) -?-

[Show 0 more parts](#)

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-?-	Name	Description	Direction	Control -?-	Output Low High	Length
<a href="#">A</a>	<a href="#">BBa_I12007</a>	Modified lambda Prm promoter (OR-3 obliterated)	Forward	cl		82
<a href="#">A</a>	<a href="#">BBa_R0062</a>	Promoter (luxR & HSL regulated -- lux pR)	Forward	luxR, HSL		55
<a href="#">A</a>	<a href="#">BBa_R0079</a>	Promoter (LasR & PAI regulated)	Forward	PAI		157
<a href="#">A</a>	<a href="#">BBa_R0080</a>	Promoter (AraC regulated)	Forward	araC		149

Available other regulators

[Show 172 more parts](#)

[Edit](#)

-?-	Name	Description	Direction	Control -?-	Output Low High	Length
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_I0500</a>	Inducible pBad/araC	Forward	araC, arabinose		1210
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_I13453</a>	Pbad promoter				130
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J13002</a>	TetR repressed POPS/RIPS generator	Forward	ATc		74
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J13023</a>	3OC6HSL+LuxR dependent POPS/RIPS generator				117
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23100</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23101</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23102</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23103</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23104</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23105</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23106</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23107</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23108</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23109</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23110</a>	constitutive promoter family member				35
<a href="#">A</a> <a href="#">W</a>	<a href="#">BBa_J23111</a>	constitutive promoter family member				35

<http://parts.mit.edu>

# BBa\_F2620

3OC<sub>6</sub>HSL → PoPS Receiver

[http://parts.mit.edu/registry/index.php/Part:BBa\\_F2620](http://parts.mit.edu/registry/index.php/Part:BBa_F2620)



Authors:  
Barry Canton [bcanton@mit.edu]  
Anna Labno [labnoa@mit.edu]

Last Update: 15 January 2007

## Description

A transcription factor (LuxR, BBa\_C0062) that is active in the presence of cell-cell signaling molecule 3OC<sub>6</sub>HSL is controlled by a TetR-regulated operator (BBa\_R0040). Device Input is 3OC<sub>6</sub>HSL. Device output is PoPS from a LuxR-regulated operator. If used in a cell containing TetR then a second Input signal such as aTc can be used to produce a Boolean AND function.

## Characteristics

**Input Swing:** 1E-9 to 1E-6 M 3OC<sub>6</sub>HSL, exogenous

**Output Swing:** 0±1 to 503±1 GFP molecules cfr<sup>-1</sup> s<sup>-1</sup>

**Switch Point:** 7±1 nM 3OC<sub>6</sub>HSL, exogenous

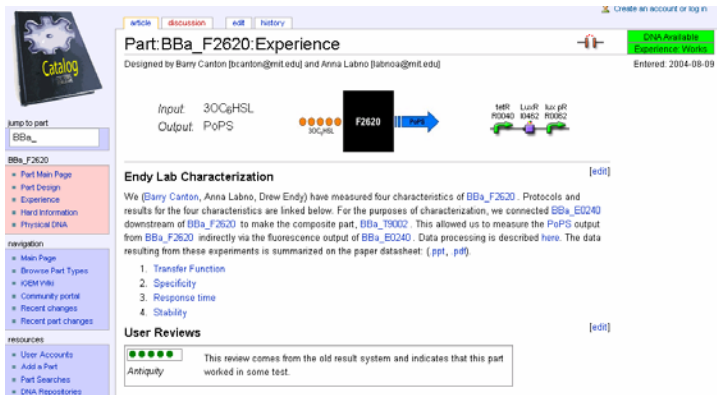
**LH Response:** 9 min (t<sub>50%</sub>), 27 min (t<sub>90%</sub>)

## Key Parts

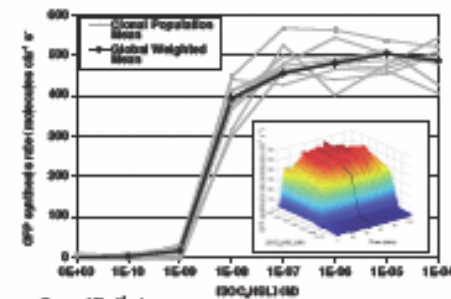
BBa\_R0040: TetR-regulated operator

BBa\_C0062: luxR ORF

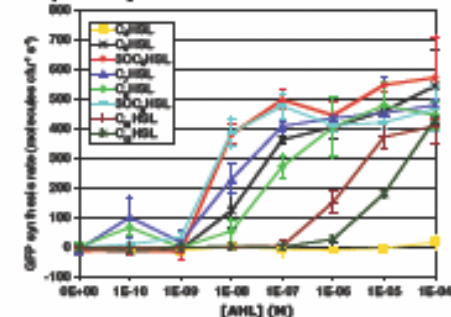
BBa\_R0002: LuxR-regulated operator



## Transfer Function\*



## Specificity\*



## Demand (low/high input)

**Translational:** 256/8048 ribosomes cfr<sup>-1</sup>  
3.8E3/1.2E5 charged tRNA cfr<sup>-1</sup> s<sup>-1</sup>

## Compatibility

**Chassis:** Compatible with MC4100, MG1655, and DHSα

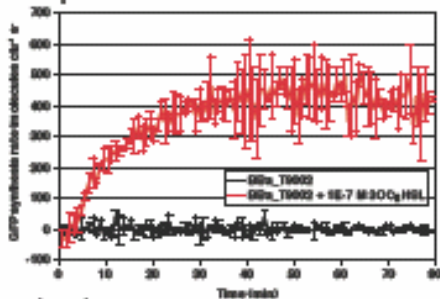
**Plasmids:** Compatible with pSB3K3 and pSB1A2

**Devices:** Compatible with E0240, E0430 and E0434

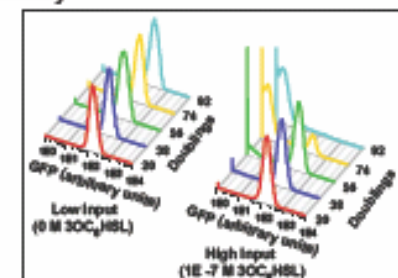
**Crosstalk:** with systems containing TetR (C0040)

**Signaling:** Crosstalk with input molecules similar to 3OC<sub>6</sub>HSL

## Response Time\*



## Stability\*\*



## Stability (low/high input)

**Genetic:** >92/74 replication events\*\*

**Performance:** >92/74 replication events\*\*

**Conditions (abridged)**

**Output:** Indirect via BBa\_E0240

**Vector:** pSB3K3

**Chassis:** MG1655

**Culture:** Supplemented M9, 37°C

**\*Equipment:** PE Victor3 plate reader

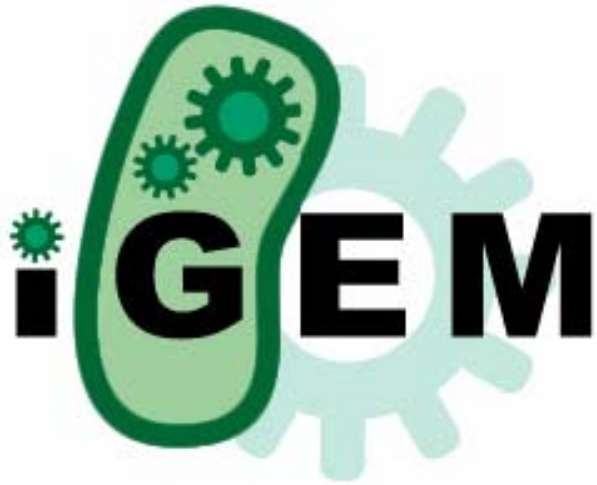
**\*\*Equipment:** BD FACScan cytometer

Signaling Devices

Registry of Standard Biological Parts

making life better, one part at a time

License: Public



Growing a community by sharing:

- Physical DNA parts (Biobricks)
- DNA code
- Protocols
- Experience
- Publications

Encourages play, independence, creativity





2006 Jamboree – 400 gengineers

## Designs on life

Earlier this month, students from around the world locked horns in competition. Their challenge was to build functioning devices out of biological parts. Erika Check finds out how they got on.

Even if you're thinking big, you usually have to start small. Especially, as a group of Swiss students found, when big means counting to infinity. The team was drawing up a blueprint for the world's first counting machine made entirely of biological parts. Although they had their sights on lofty numbers, they opted to go no higher than two. If the plan worked, it would be a proof-of-principle for a much larger tallying device.

The group, from the Federal Institute of Technology (ETH) in Zurich, was one of 17 teams unveiling their projects at the first international Intercollegiate Genetically Engineered Machine (iGEM) competition, held at the Massachusetts Institute of Technology (MIT) in Cambridge on 5 and 6 November. The event attracted students from all over the world to design and build machines made entirely from biological components such as genes and proteins. They drew up grand designs for bacterial lach-2-shakes, phorbol-1-shakes, thermometers and sensors. And if none of the designs succeeded completely, that was more because of the limitations of the nascent science of synthetic biology than any lack of enthusiasm, creativity or hard work.

Synthetic biology aims to merge engineering approaches with biology. Researchers working at the most basic level are copying simple biological processes, such as the production of a protein from a gene. They break the process down into its component elements, such as a gene and the pieces of DNA and other molecules that control its activity. They then string these elements together to build a module they know will behave in a particular way — say, oscillate between producing and not producing a protein, or produce a protein that can switch another module on or off.

It is these kinds of components — oscillators and switches — that engineers order from suppliers and link together to build more complex electronic circuits and machines. Synthetic biologists are trying to develop a similar array of biological components, dubbed BioBricks, that can be inserted into any genetic circuit to carry out a particular function. Scientists at MIT have established a Registry of Standard Biological Parts, a catalogue of BioBricks that theoretically



Bidding for glory: teams from the ETH Zurich (top), Cambridge, UK, (bottom right) and Massachusetts at the first international Intercollegiate Genetically Engineered Machine competition.

selection of designs. Students from the University of Cambridge, UK, tried to make a circuit that could control the movement of *Escherichia coli* bacteria. They aimed to engineer the bacteria to contain a switch governing their sensitivity to the sugar maltose. With the switch off, the microbes would ignore the sugar. Tipping

Compe Much 1 student iGEM curious to learn



work, new center to focus on synthetic biology



## BRIEF COMMUNICATIONS

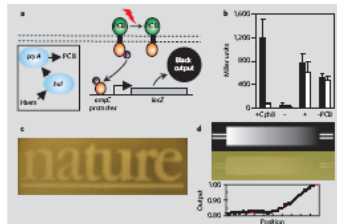
### Engineering *Escherichia coli* to see light

These smart bacteria 'photograph' a light pattern as a high-definition chemical image.

We have designed a bacterial system that is switched between different states by red light. The system consists of a synthetic sensor kinase that allows a lawn of bacteria to function as a biological film, such that the projection of a pattern of light on to the bacteria produces a high-definition (about 100 megapixels per square inch), two-dimensional chemical image. This spatial control of bacterial gene expression could be used to 'print' complex biological materials, for example, and to investigate signalling pathways through precise spatial and temporal control of their phosphorylation state.

Plants and some bacteria use a class of protein photoreceptors known as phytochromes to control photomorphogenesis and the production of protective pigments<sup>1</sup>. Photoreceptors are not found in eukaryotes, such as *Escherichia coli*, so we created a light sensor that functions in *E. coli* by engineering a chimera that uses a phytochrome from a cyanobacterium.

A phytochrome is a two-component system that consists of a membrane-bound, extracellular sensor that responds to light and an intracellular response-regulator. The response-regulator of most phytochromes do not have DNA-binding domains and do not directly regulate gene expression, so we fused a cyanobacterial photoreceptor to an *E. coli* intracellular histidine kinase domain (Fig. 1a, and see supplementary information). This design was based on the well-studied *E. coli* EnvZ-OmpR two-component system, which normally regulates porins expressed in response to osmotic shock<sup>2</sup>. The EnvZ histidine kinase domain has been used for the construction of functional chimeras<sup>3,4</sup>, and a plant phytochrome has



**Figure 1** Light images by using red fluorescent cells. **a**, The chimeric light receptor Cph1 contains the photoreceptor from *Red* (green) and the histidine kinase and response-regulator from *EnvZ*-OmpR (orange). Upon conversion of the sensor to phytochrome (PCB), which forms part of the photoreceptor, the light drives the sensor to a state which strongly phosphorylates the response-regulator, turning off gene expression. For details of genes, see text. **b**, Miller assay showing that Cph1 is activated in the dark (black bar) in the presence of PCB and inactivates in the light (white bar). There is a light-dependent activity in the absence of Cph1 (—) which is a constitutive activity when the bacteria have been grown in the presence of PCB. **c**, When an image is projected on to the bacterium, the EnvZ reporter is expressed. **d**, Transverse section of the circuit. As the intensity of the light is increased, the circuit output goes from a high to a low state.

enzymatically produces a black compound. The part of the photoreceptor that responds to light, phytochrome, is not naturally produced in *E. coli*. We therefore introduced two phytochrome-kinase domain pairs (hck and pck) from *Synechocystis* but converted them into phytochromes (parts 1, 1150A, B, 1150B, MIT Registry of Standard Biological Parts) (Fig. 1a, inset). Individual Cph1-EnvZ chimeras were then fused at 37 °C for 4 h with broad-spectrum light and assayed for expression of lacZ reporter. The chimera Cph1-1150B produced a particularly strong response to light (Fig. 1b).

For bacterial photography, we grew a lawn of bacteria on agar. The lacZ reporter was induced by addition of 5-gal (5,4-cyanoheptatriene-β-D-galactopyranoside). LacZ types the formation of a stable, insoluble, X precipitate from 5-gal. Light induced an expression in the bacteria, giving a contrast replica of the applied image on

the biological film. In this experiment, we used a 100-watt halogen lamp (Fig. 1c, and see supplementary information). The lacZ activity shows the resulting light image (Fig. 1c, inset). The light intensity should be spatially and temporally controlled to be applied to the bacteria and to the potential application in photography, manufacture of computer and the signalling network.

Andrew Linker, Aaron J. Silver, Zachary Smith, Lawrence, Matthew Levy, Alexander Sorenson, and Edward M. Marcovitz, *E. coli*



## Genetic 'Jamboree' draws innovators

## Science students the world over share research



At MIT's International Genetically Engineered Machine Competition yesterday, the audience listened to a presentation on synthetic biology. (John Tlumacki/Globe Staff)

## COVER STORY

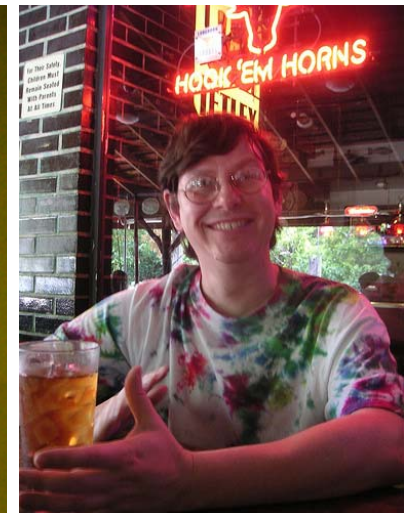
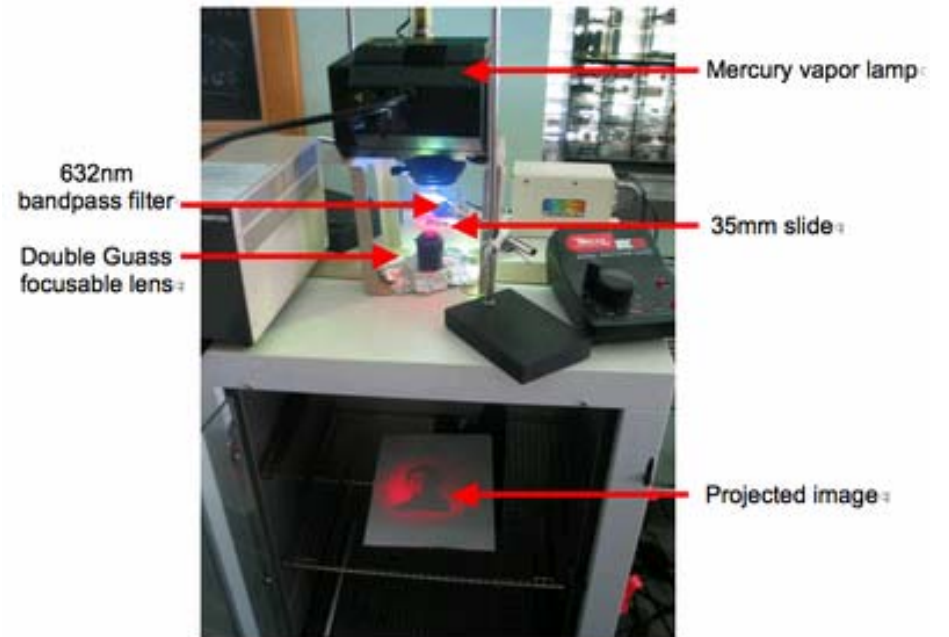
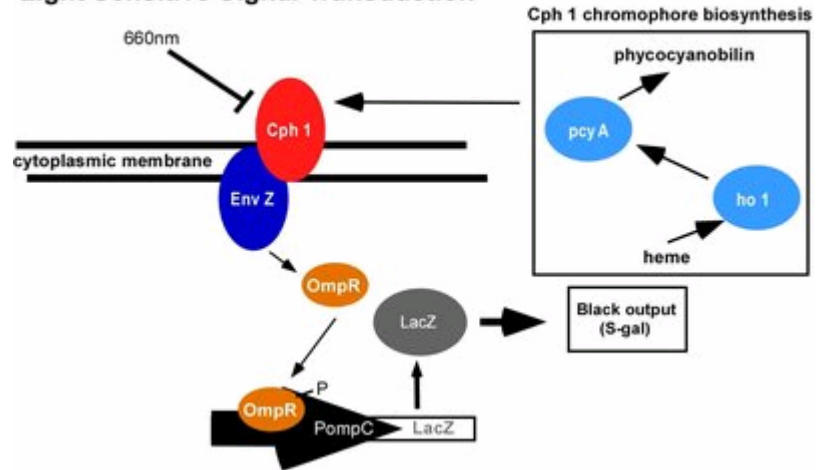
By Carl Zimmer

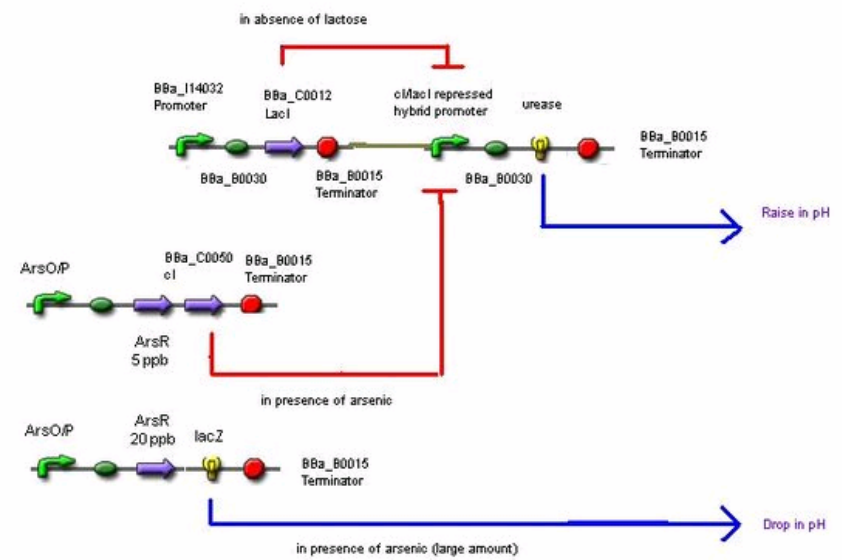
### Scientist of the Year

Jay Keasling is developing ways to program DNA as easily as people program computers.



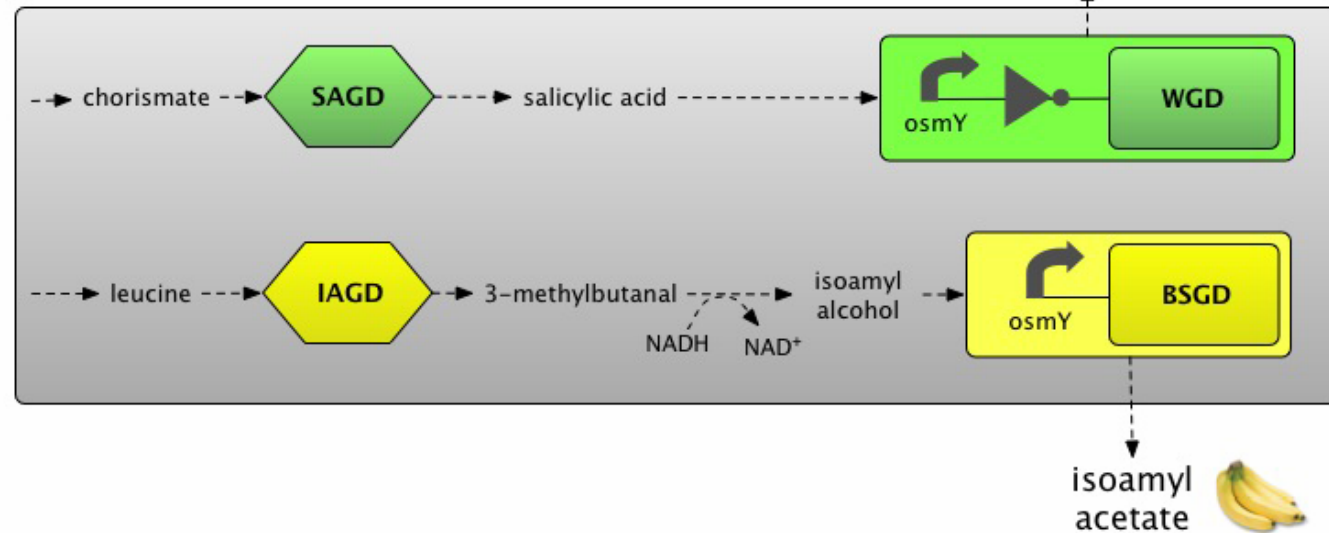
## Light Sensitive Signal Transduction







## indole deficient tnaA5<sup>-</sup> chassis



# iGEM 2007

- 57 teams – 20 countries
- USA (26)
- Scotland (3)
- Colombia
- Italy (2)
- Mexico
- Taiwan
- Russia
- Germany
- South Africa
- Middle East
- Canada (6)
- Japan (2)
- Australia
- England
- Switzerland
- China (4)
- Spain
- India
- France
- **Slovenia**

# U of A iGEM Team

- Biobutanol project – “*Plan B*”
- Moving metabolic pathway from *Clostridium* into *E. coli*



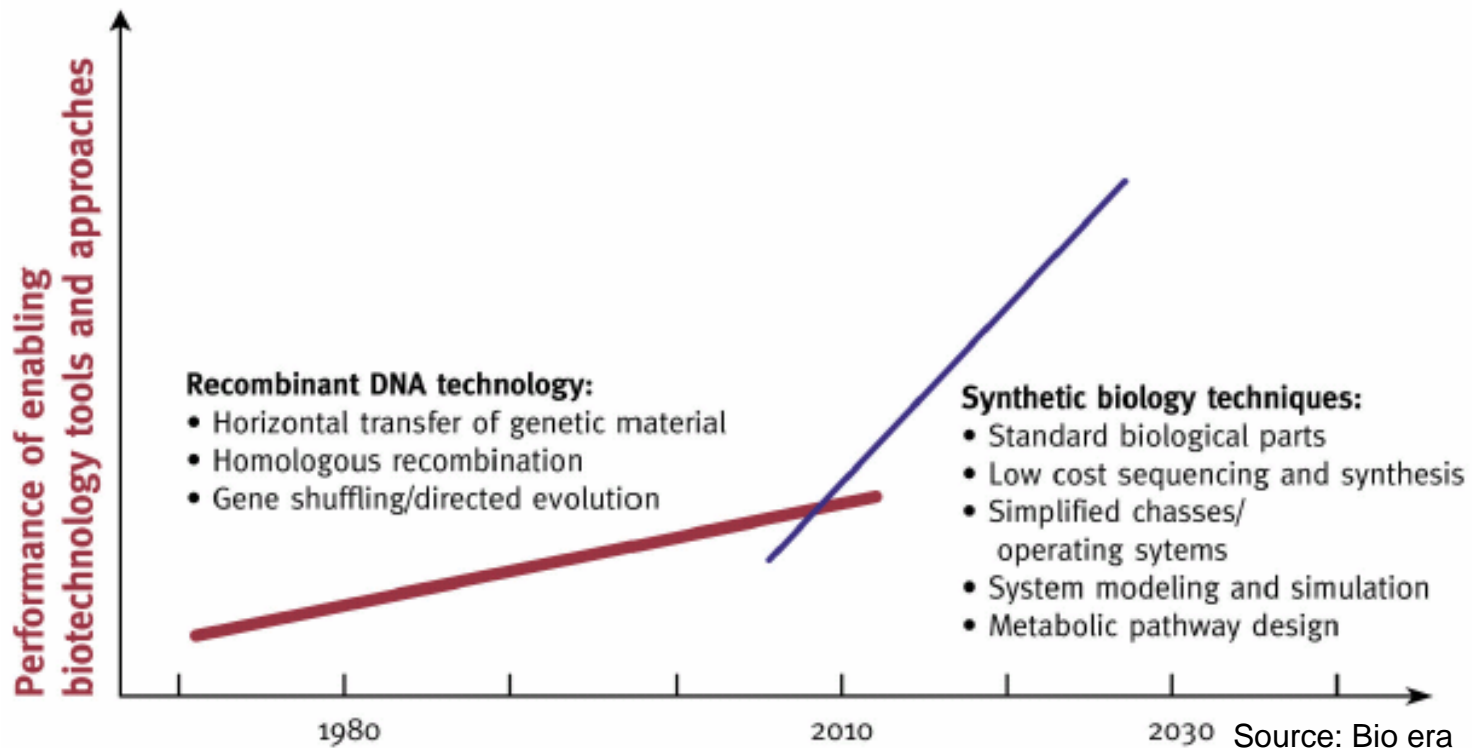
# U of C iGEM team

- Combination of mechanical and biological devices
- 2D plotter system
- Switched agarase activation
- Allows precise “carving” of agarase medium



# Opportunities for Alberta

# Synthetic biology is going to grow fast!



# PIMP MY GENOME!

SYNTHETIC BIOLOGY:  
A PLAN FOR ENGINEERING BIOLOGY



Wednesday April 4, 2007

University of Alberta, Telus Centre, Room 150  
111 Street and 87 Avenue  
Edmonton, AB

Doors open and refreshments - 3:00 PM

Presentation - 3:30 PM

*Complimentary return bus transportation will be provided  
to guests from the University of Calgary.*

Join Drew Endy, a leader in synthetic biology from MIT, for an engaging look at how biological engineering is changing. Find out how the latest advances in this new era of biology are helping make R&D faster, cheaper and easier.

Drew is a fellow in the Department of Biology and the Biological Engineering Division at MIT. He co-founded the MIT Synthetic Biology working group and the Registry of Standard Biological Parts. He is also co-founder of iGEM, the International Genetically Engineered Machine competition, Codon Devices Inc., a venture-funded startup that is working to develop next-generation DNA synthesis technology, and the BioBricks Foundation, a not-for-profit organization that is working to develop legal and economic strategies needed to support open biotechnology. Drew's work has been featured in *The Economist*, *Forbes*, *Wired*, *Schematic American* and the *New York Times*.

For registration and more information,  
please visit [www.albertaingenuity.ca](http://www.albertaingenuity.ca).



The Alberta Ingenuity Fund supports science and engineering research of the highest calibre to create a prosperous future for the province. It draws funding from a \$7 billion endowment established and managed by the Government of Alberta to build the capacity for innovation, especially in areas with long lasting social and economic impact.

*Engineering synthetic biological constructs will become the foundational technology of the 21<sup>st</sup> century* Tom Knight, MIT, SB3

- Biology > Physics (\$, staff, discoveries)
- Biology is more important than physics, as measured by its economic outputs, ethical implications, and effects on human welfare
- Alberta already *has* a vibrant bio-economy
- Well-positioned to become a global leader in synthetic biotechnologies *if we act quickly and decisively*
- DNA has always been high impact, and this is a ground-floor opportunity

# We need to start education programs and do outreach...



A JOINT PROGRAM OF THE CALIFORNIA INSTITUTE FOR QUANTITATIVE BIOMEDICAL RESEARCH (QB3)  
AND LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL)

The California Institute for Quantitative Biomedical Research (QB3) and Lawrence Berkeley National Laboratory (LBNL) have joined forces to accelerate the growth of synthetic biology, a new field that promises major new advances in preventing and treating disease, generating new energy sources, and preventing and mitigating environmental threats.

Opening in spring 2005 in a spacious, modern building in west Berkeley, the Berkeley Center for Synthetic Biology gives renowned scientists and engineers the chance to pool their talents and collaborate in new ways with enormous potential benefits for California's advances in biomedicine and economic growth.

the control and design of  
id new organisms to solve a  
energy, and environmental  
solved using naturally  
as. The inherently



QB3 and LBNL scientists occupy lab space in a building renovated in 1997 for biotech research, previously leased by Bayer, featuring large labs, viral suites, and tissue culture rooms. UCSF Mission Bay and numerous biotech firms are nearby.

## MIT establishes groundbreaking biological engineering major

February 17, 2005

The Massachusetts Institute of Technology faculty yesterday approved a new course of study for undergraduates, in biological engineering, the first entirely new curriculum established at the Institute in 29 years.

## California Institute for Quantitative Biomedical Research



### **2/1/2007 - BP awards \$500 million bioenergy grant**

Global energy firm BP has selected UC Berkeley, in partnership with Lawrence Berkeley National Laboratory and the University of Illinois, to lead an unprecedented \$500 million research effort to develop new sources of energy and reduce the impact of energy consumption on the environment. The funding will create the Energy Biosciences Institute, which initially will focus its research on biotechnology to produce biofuels. QB3 helped coordinate the research proposal and will help administer the project. [More](#) >



### **6/26/2007 - Bay Area partnership to host DOE bioscience center**

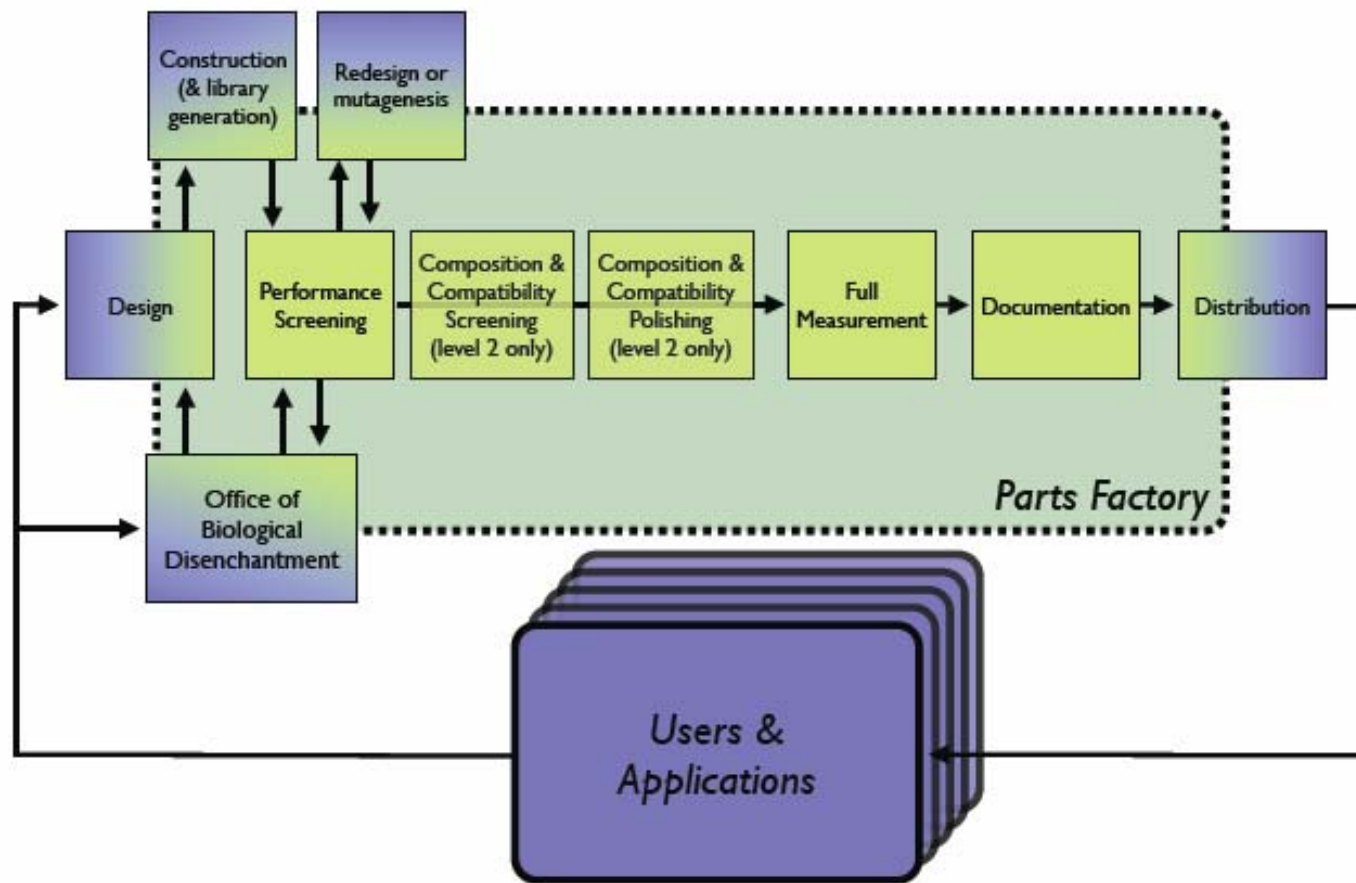
The U.S. Department of Energy has announced the creation of a new bioenergy research center, with UC Berkeley and Lawrence Berkeley National Laboratory as two of its six collaborating institutions. The Joint BioEnergy Institute – to be headquartered in the East Bay and led by Jay Keasling – will receive approximately \$125 million in DOE funding over five years. [More](#) >



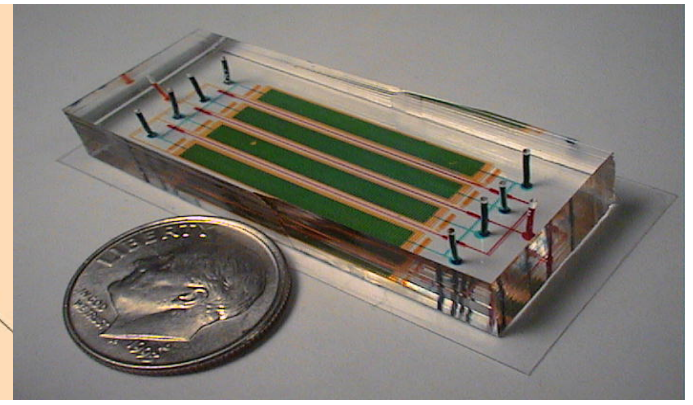
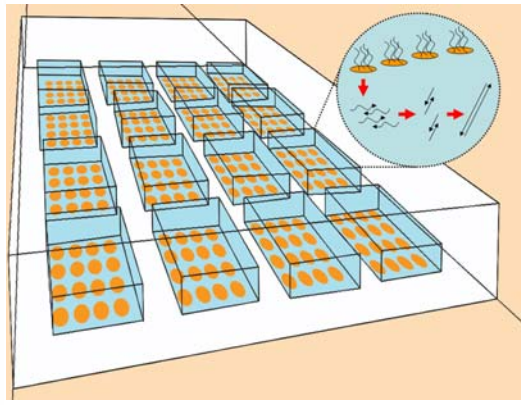
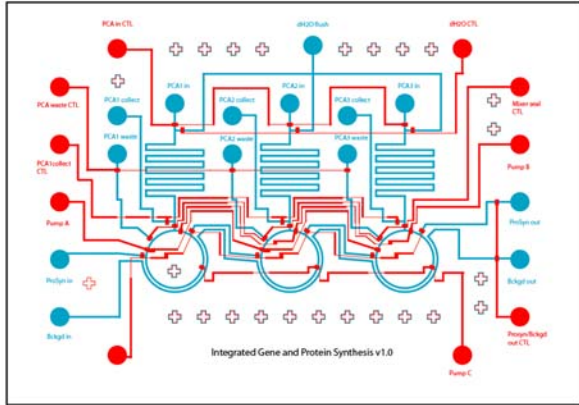
### **8/3/2006 - New center poised to transform biotech**

Aided by a \$16 million NSF grant, QB3 has launched the Synthetic Biology Engineering Research Center at UC Berkeley, with collaborators at UC San Francisco, MIT, Harvard, and Prairie View A&M University. Researchers hope to make it as quick and easy to engineer biology as it now is to assemble microprocessors, hard drives, and memory chips into a computer. [More](#) >

# Build a bio-fab to support research community and next-gen companies



# Nanoscale biology



Christian Hilty is a member of the Alexander Pines research group and principal author of a paper in which it was demonstrated that Nuclear Magnetic Resonance or NMR spectroscopy can be used with microfluidic "lab-on-a-chip" devices.

## IBM's nanoscale MRI breakthrough

By Stephen Withers

Monday, 23 April 2007

**Researchers at IBM's Almaden Research Center have demonstrated 2D magnetic resonance imaging of nanoscale objects as small as 90nm.**





Monday, April 09, 2007

## DNA Factories

Cheaply churning out made-to-order DNA could revolutionize molecular biology.

By Emily Singer

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**LS9, INC.**  
the renewable petroleum company™



# Archemix

The Aptamer Therapeutics Company™



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Realizing the Promise of Synthetic Biology

[COMPANY PROFILE](#)

[TECHNOLOGY](#)

[CURRENT PROJECTS](#)

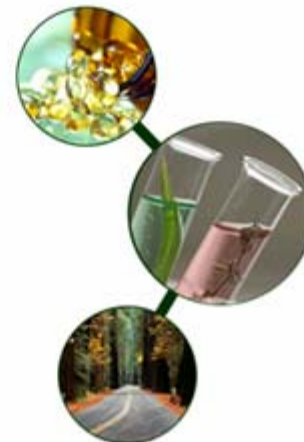
[NEWS](#)

[CAREERS](#)

## Welcome



Amyris Biotechnologies is translating the promise of synthetic biology into solutions for real-world problems. Building on advances in molecular, cell and systems biology, we are engineering microbes capable of producing high-value compounds to address major global health and energy challenges. We are employing these living chemical factories to produce novel pharmaceuticals, renewable fuels, and specialty chemicals.



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- \*Applications (health, biofuels, bioproducts)
- Software: Metabolic and genomic design tools
- Hardware: Advanced synthesis hardware, biological test and measurement devices
- Ethics and social policy of synthetic biology
- Educational program development
- Next-generation biotechnology company development



MAY 3, 1982

\$1.50

# TIME

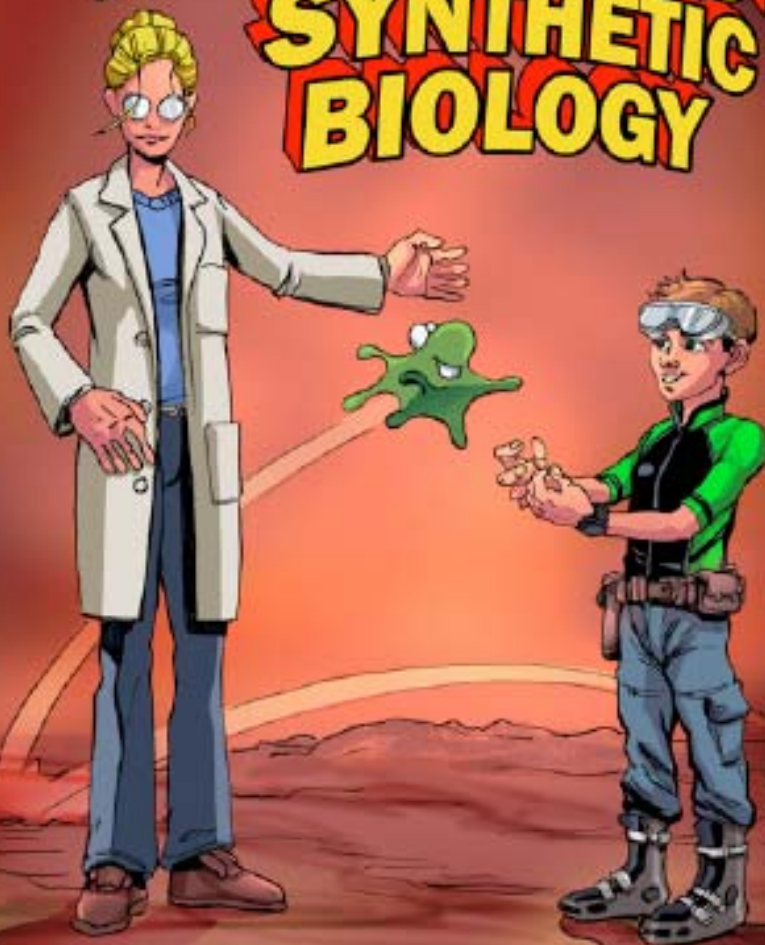
## COMPUTER GENERATION

A New Breed of Whiz Kids

**-3%**  
INFLATION VANISHES!  
At Least for  
A Month



# ADVENTURES IN SYNTHETIC BIOLOGY



STORY: DREW ENDY ISADORA DEESE  
THE MIT SYNTHETIC BIOLOGY WORKING GROUP  
ART: CHUCK WADEY [WWW.CHUCKWADEY.COM](http://WWW.CHUCKWADEY.COM)

## ENGINEERED GENETIC DEVICES

LET ME INTRODUCE YOU TO A FRIEND OF MINE. IT'S CALLED AN INVERTER DEVICE.

I KNOW BACTERIA BALLOONS COULD WORK -  
-IF ONLY THERE WAS SOME WAY TO STOP THEM FROM GROWING UNTIL THEY EXPLODE!

IT COULD BE THE ANSWER YOU'RE LOOKING FOR.

GEE, THANKS FOR TELLING ME AHEAD OF TIME!

WHAT THE HECK IS AN INVERTER?!

OK, PAY ATTENTION! AN INVERTER IS A COMBINATION OF BASIC DNA PARTS THAT -

-WORKING TOGETHER, TURN SOMETHING UPSIDE DOWN.

ON BECOMES OFF, LOW BECOMES HIGH, AND SO ON.

### Parts of an Inverter

1. **Ribosome Binding Site (RBS)** - Basic elements that start the process of protein synthesis.
2. **Repressor** - A gene that encodes a particular type of protein that will bind DNA sites in a specific Operator part and cause changes in the rate of gene expression.
3. **Terminator** - Special elements that decrease the flow of RNA polymerase along DNA, sometimes to zero!
4. **Operator** - Stretches of DNA that contain Repressor protein binding sites and RNA polymerase binding and initiation sites. With a Repressor protein, the Operator part will be turned OFF. Without a Repressor protein, the Operator part will be turned ON, allowing RNA polymerase to bind and initiate a HIGH output signal.

YOU COULD HAVE USED AN INVERTER DEVICE TO HELP PREVENT BUDDY'S UNFORTUNATE ACCIDENT.

UHM... WHY'S IT CALLED A DEVICE?

IT'S ENOUGH YOU'RE A KNOW-IT-ALL, YOU DON'T HAVE TO RUB IT IN.

YOU'D PREFER THING-ANAJISSY?

WE CALL AN INVERTER A DEVICE IN ORDER TO HIDE ALL THE DETAILS OF HOW IT WORKS.

FOR EXAMPLE, HERE'S SOME DNA CODE -

-NOW YOU TELL ME WHAT IT DOES!

HEY! WATCH IT!

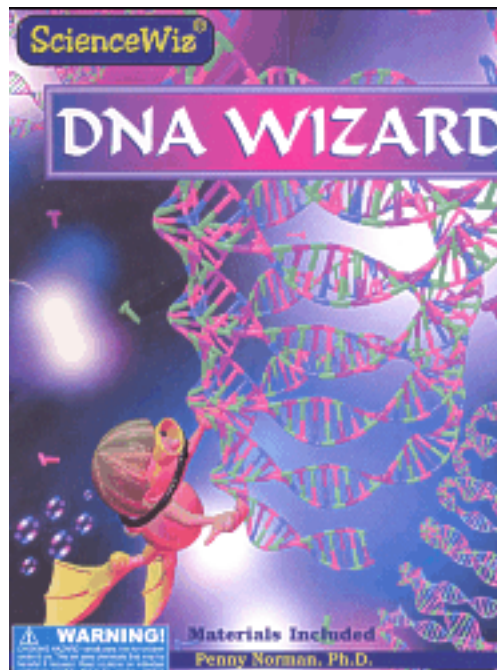
I HAVE NO IDEA, OK? WHAT IS IT?

DON'T FEEL BAD. MY POINT IS, YOU SHOULDN'T HAVE TO MEMORIZE EVERY LAST PIECE OF DNA.

WE'RE GOING TO HIDE ALL THESE DETAILS INSIDE THE DEVICE.

PHEN -

HOW DID YOU DO THAT?



# Projects with DNA

For ages 8 and up  
Adult Supervision Required

Materials included except for the items listed.  
Through play, hands-on projects, patterns and puzzles  
this book and kit explores the amazing DNA story.

**Extract DNA**

**Heat SHOCK!**

**Decode the code of life**

**Build a DNA ladder.**

**Grow glowing cells**

**Is it a boy or girl?**

**Ooey, Gooley, DNA!**

**Solve the chromosome puzzle.**

**Dress up for sterile techniques.**

Quality time, quality learning, quality play.